Lecture 16- Notes

- DC LOAD LINE

1) $V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$ (KVL @ the output loop)

ASSUMING FORWARD ACTIVE MODE $I_C \simeq I_E$. THUS

2) $V_{CC} - I_C R_C - V_{CE} - I_C R_E = 0$

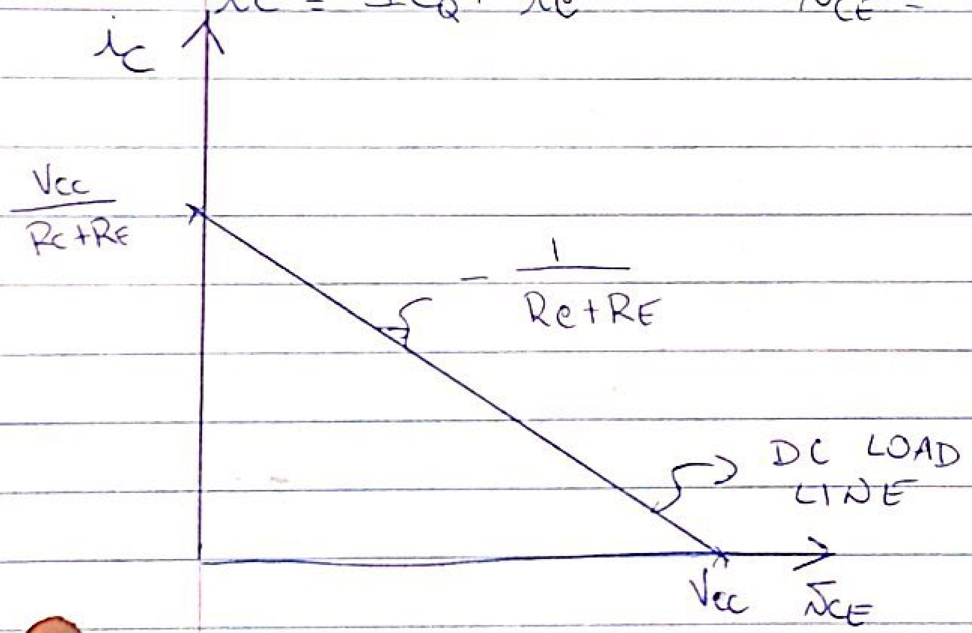
3) $$I_C = -\frac{V_{CE}}{R_E + R_C} + \frac{V_{CC}}{R_C + R_E}$$

4) $I_C = 0 \Rightarrow V_{CE} = V_{CC}$

5) $V_{CE} = 0 \Rightarrow I_C = \dfrac{V_{CC}}{R_C + R_E}$

IT IS USEFUL TO SKETCH THE LOAD LINE IN THE $i_C - v_{CE}$ (AC+DC) SPACE.

$i_C = \overset{DC}{I_{C_Q}} + \overset{AC}{i_c}$ $\qquad v_{CE} = V^{DC}_{CE_Q} + \overset{AC}{v_{ce}}$



- AC LOAD LINE

7) $i_e = -\frac{v_{ce}}{r_e} = -\frac{v_{ce}}{R_e \| R_L}$

IT IS USEFUL TO SKETCH THE AC LOAD LINE IN THE $i_C - v_{CE}$ Space. AGAIN

8) $i_C = I_{CQ} + i_e$

9) $v_{CE} = V_{CEQ} + v_{ce}$

From (8)

10) $\overset{AC}{i_e} = i_C - \overset{DC}{I_{CQ}}$

From (9)

11) $\overset{AC}{v_{ce}} = v_{CE} - \overset{DC}{V_{CEQ}}$

COMBINING (10) AND (11) WITH (7) WE OBTAIN

12) $i_C - I_{CQ} = -\frac{v_{CE} - V_{CEQ}}{R_e \| R_L}$

13) $i_C = -\frac{v_{CE} - V_{CEQ}}{R_e \| R_L} + I_{CQ}$

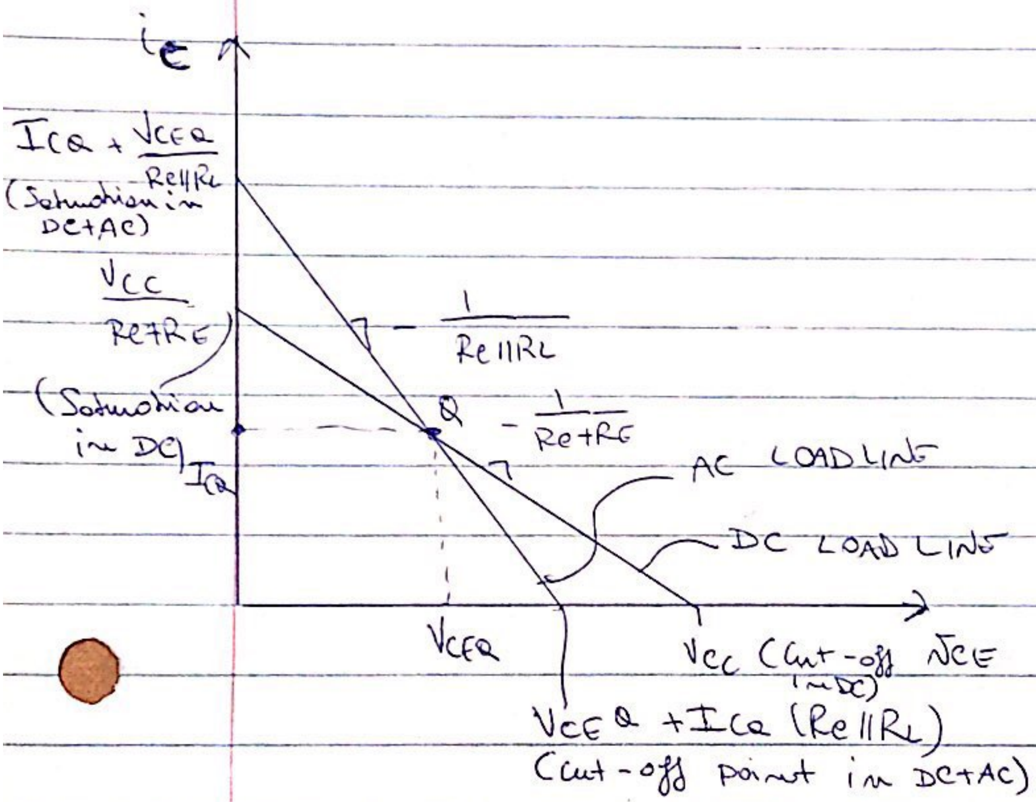
Now, to sketch the load line in the $i_C - v_{CE}$ space we need to determine the intercepts of the line with the i_C and the v_{CE} axis.

$i_C = 0 \Rightarrow \frac{v_{CE} - V_{CEQ}}{R_e \| R_L} = I_{CQ} \Rightarrow v_{CE} = V_{CEQ} + I_{CQ} (R_e \| R_L)$

14) $v_{CE} = V_{CEQ} + I_{CQ} (R_e \| R_L)$

$v_{CE} = 0 \Rightarrow I_{CQ} + \frac{V_{CEQ}}{R_e \| R_L}$

15) $i_c = I_{CQ} + \frac{V_{CEQ}}{Re \parallel R_L}$



$v_{CE} \uparrow$ THE BJT IS GETTING CLOSE TO CUT-OFF

$v_{CE} \downarrow$ THE BJT IS GETTING CLOSE TO SATURATION

Cut-off limit $\quad v_{CE} = I_{CQ}(Re\parallel R_L)$ Upper limit

$v_{CE_{pp}} = 2 I_{CQ}(Re\parallel R_L)$ Symmetrical swing limit

Saturation limit $\quad v_{CE} = V_{CEQ}$ Lower limit

$v_{CEpp} = 2 V_{CEQ}$ Symmetrical swing limit

$V_{CEQ} \leq v_{CE} \leq I_{CQ}(Re\parallel R_L)$ Compliance or swing

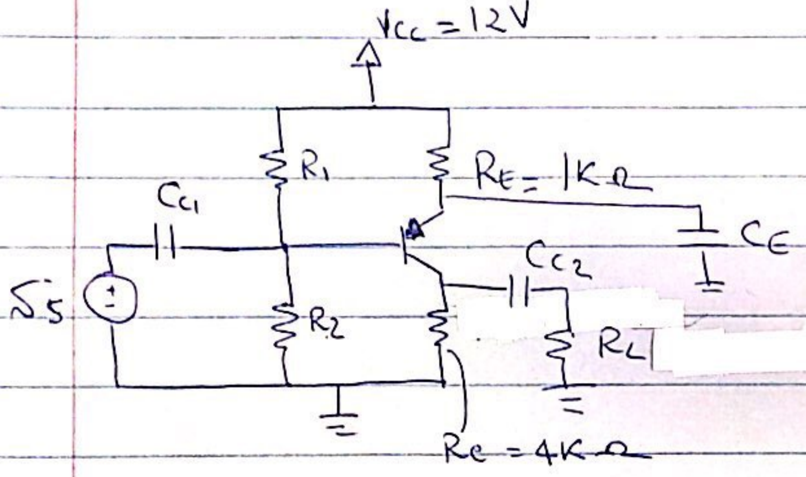
Smallest between

$2 I_{CQ}(Re\parallel R_L)$ and $2 V_{CEQ}$

Cut-off limit is more stringent at large V_{CEQ} and low I_{CQ}

The saturation limit is more stringent at low V_{CEQ} and high I_{CQ}.

Lecture 16 - In class problem - Solution



$\beta = 120$
$V_{EB} = 0.7\,V$
$r_o = \infty$

a) Design a bias-stable circuit such that $I_{CQ} = 1.6\,mA$. Determine V_{CEQ}.

For a CE amplifier, we have previously determined a condition of bias stable circuit:

$$R_{TH} = 0.1\,(1+\beta)\,R_E \Rightarrow R_{TH} = 0.1\,(121)\cdot 1K = 12.1\,k\Omega$$

where R_{TH} is the Thevenin equivalent resistance looking away from the base: $R_{TH} = R_1 /\!/ R_2 = \dfrac{R_1 R_2}{R_1 + R_2}$

$$V_{TH} = \frac{V_{CC}\,R_2}{R_1+R_2} = \frac{V_{CC}\,R_1 R_2}{R_1(R_1+R_2)} = \frac{V_{CC}\,R_{TH}}{R_1}$$

$$R_1 = \frac{V_{CC}}{V_{TH}} \cdot R_{TH}$$

We need to determine V_{TH} - Once we'll have done that we will be able to calculate R_1 and R_2 (given that R_{TH} is known)

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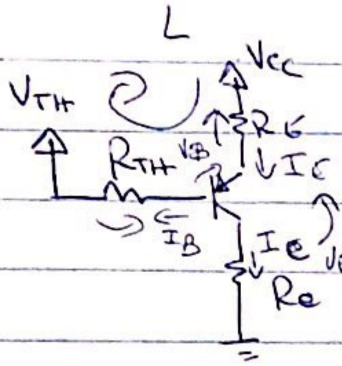


KVL @ L:

$$V_{CC} - R_E I_E - V_{EB} - R_{TH} I_B - V_{TH} = 0$$

$I_E = (\beta+1) I_B$ (ASSUMING F.A. MODE)

$$V_{CC} = R_E I_B(\beta+1) + V_{EB} + R_{TH} I_B + V_{TH}$$

$$I_C = 1.6mA \Rightarrow I_B = \frac{1.6m}{120} = 0.0133\,mA$$

$$I_B = \frac{V_{CC} - V_{EB} - V_{TH}}{R_{TH} + R_E(\beta+1)}$$

$$I_B = \frac{V_{CC} - V_{EB} - \frac{1}{R_1} \cdot R_{TH} \cdot V_{CC}}{R_{TH} + R_E(\beta+1)}$$

$$I_B = 0.0133m = \frac{12 - 0.7 - \frac{1}{R_1}(12.1k)(12)}{12.1k + (121)\cdot 1k} \Rightarrow R_1 = 15.24k$$

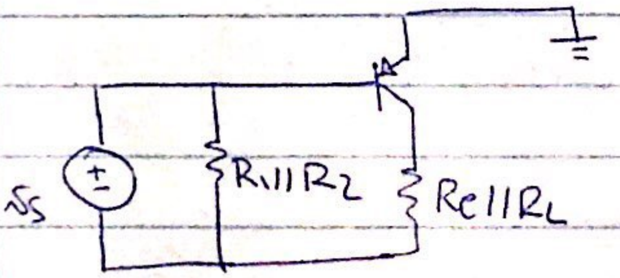
$$R_{TH} = 12.1k = \frac{15.24k\Omega \cdot R_2}{15.24k\Omega + R_2} \Rightarrow R_2 = 58.7k\Omega$$

$$V_{ECQ} = V_{CC} - I_C \cdot R_C - I_E R_E = 12 - (R_C + R_E) I_C =$$

$$= 12 - (4k + 1k)(1.6m) = 3.99\,V$$

$V_{CEQ} > V_{CESAT}$ THE BJT IS IN F.A. MODE AS ASSUMED.

b) Determine the maximum symmetrical swing of the output voltage for a load $R_L = 8\,\Omega$.
The BJT going out of forward active mode is responsible for limiting the swing at the output. Thus, to determine the maximum symmetrical swing we need to specify the conditions at which the BJT goes into saturation and cut-off. We will then focus on the most stringent of the two to determine the maximum symmetrical swing.
Sketching the AC load line is a way to easily specify the conditions for cut-off and saturation in terms of total (DC+AC) signals.



AC CIRCUIT

The KVL @ output branch yields the AC load line:

$$(R_C \| R_L)\, i_c + v_{ec} = 0 \Rightarrow$$

$$\Rightarrow i_c = -\frac{v_{ec}}{R_C \| R_L}$$

Using the load line we will now determine the conditions of cut-off and saturation for the BJT in terms of the total collector current (i_C = DC+AC) and the total v_{EC} (v_{EC} = DC+AC).

$i_C = I_{CQ} + i_c$ $\quad$ $v_{EC} = V_{ECQ} + v_{ec}$

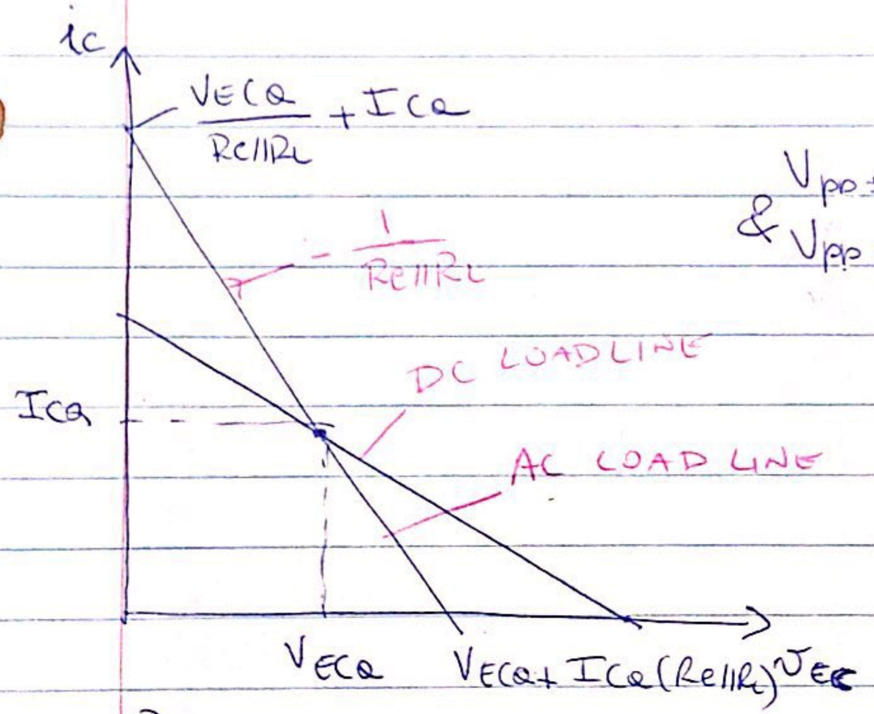
$i_c = i_C - I_{CQ}$ $\quad v_{ec} = -V_{ECQ} + v_{EC}$

By plugging the expressions above into the equation of the AC load line we get

$$i_C - I_{CQ} = -\frac{v_{EC} - V_{ECQ}}{R_e \| R_L}$$

$$v_{EC} = 0 \Rightarrow i_C = \frac{V_{ECQ}}{R_e \| R_L} + I_{CQ}$$

$$i_C = 0 \Rightarrow v_{EC} = I_{CQ}(R_e \| R_L) + V_{ECQ}$$



$\underbrace{V_{pp} \le 2V_{ECQ}}_{V_{pp\,SAT}}$

& $V_{pp} \le \underbrace{2\, I_{CQ}(R_e \| R_L)}_{V_{pp,\,cut\text{-}off}}$

$R_L = 8\,\Omega$

$R_e \| R_L \simeq R_L$ $\quad V_{pp_{SAT}} = 2V_{ECQ} = 2 \cdot 3.88\,V = 7.88\,V$

$V_{pp_{cut\text{-}off}} \simeq 2 I_{CQ} \cdot R_L = 2 \cdot 1.6m \cdot 8 =$

$= \underline{0.025\,V}$

The maximum symmetrical swing is $0.025\,V =$
$= 25\,mV$ for $R_L = 8\,\Omega$

$R_L = 5\,k\Omega$

$$R_C \parallel R_L = \frac{R_C R_L}{R_C + R_L} = \frac{20K \cdot \cancel{K}}{5\,K} = 2.2\,K\Omega$$

$V_{pp\ SAT} = 7.98\ V$

$V_{pp\ cut\text{-}off} = 2 \cdot I_{CQ} R_L = 2 \cdot 1.6m \cdot 2.2k = 7.1V$

The maximum symmetrical swing for $R_L = 5K\Omega$ is $7.1\ V$.